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Stochastic dark energy from inflationary quantum fluctuations

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Abstract We study the quantum backreaction from inflationary fluctuations of a very light, non-minimally coupled spectator scalar and show that it is a viable candidate for dark energy. The problem is solved by suitably adapting the formalism of stochastic inflation. This allows us to self-consistently account for the backreaction on the background expansion rate of the Universe where its effects are large. This framework is equivalent to that of semiclassical gravity in which matter vacuum fluctuations are included at the one loop level, but purely quantum gravitational fluctuations are neglected. Our results show that dark energy in our model can be characterized by a distinct effective equation of state parameter (as a function of redshift) which allows for testing of the model at the level of the background.

1 Introduction

The origin of dark energy (DE) is one of the most fascinating unsolved problems of modern science. In literature traditionally two main classes of solutions have been proposed [1–9]:

- **matter condensates or physical DE**, of which the simplest representatives are scalar condensates (*quintessence* models);
- **modified gravity or geometrical DE**, which mimics dark energy by changing the relation between geometry and matter or by supplying additional geometric fields to general relativity.

However, there is no impenetrable barrier between these two possibilities, and more generically DE can be both physical and geometrical, i.e. a new matter field has to be introduced and gravity becomes modified, too. This just happens in the case of DE described by a non-minimally coupled scalar field considered in this paper. Recently the effective field theory (EFT) approach to dark energy [2,5,10] has been developed. Its beauty is in that it presents a unified framework for both approaches, but its drawback is in that it does not immediately select the fundamental theory that lies behind some EFT. Nevertheless, different theories can be mapped onto the same class of EFTs, such that one can think of EFTs as identifying universality classes associated with DE models.

The question of naturalness of initial conditions is not addressed in traditional approaches. For example, in quintessence models typically a quintessence field starts running from a value which is not a (local or global) minimum of the potential. Criticisms are often brushed away by noting that similar malady plagues most of inflationary models. Arguably the main benefit of this work is in that we construct a theory that naturally explains the initial field value – which is accounted for by the calculable amplitude of infrared field fluctuations during inflation – thus addressing this fundamental criticism. The program advocated here can be thought of as a third way for understanding DE, in that in our class of models a link is established between primordial inflation and dark energy. This link, among other things, can be exploited when designing tests for these models.

Observers have devoted a lot of effort (and observational time) to nail down as accurately as possible the amount (and distribution) of dark energy. Since its discovery in 1998 [11,12] a lot of progress has been made in improving the accuracy of DE measurements [13–15]. At this moment the Planck satellite [16,17] and the Dark Energy Survey (DES) [19] collaborations provide the most stringent bounds on dark energy. Presently ΛCDM, which assumes a cosmological constant equation of state $p = -\rho$ for dark energy, is consistent with all astronomical data. Assuming a general

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